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Can the area of organically cultivated arable land increase when utilizing perennial grasses as feedstock for biogas production?

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***Abstract** - This paper investigates how the use of legumes (here perennial grasses) as feedstock for organic biogas production, can enhance the share of organic farmland, increase the arable soil quality by various Eco System Services (ESS) and provide renewable energy based on a more sustainable and readily available biomass feedstock; grass-clover. With an analytical framing taking point of departure in the concept of sustainability, and with data retrieval from both primary and secondary empirical data, the paper proposes on a new 'organic-agricultural-biogas'-system facilitating internal farm supply of biogas feedstock and the production of valuable digestate (soil fertilizer). When utilizing between 15-20 % of the farmland for perennial crop rotation a more self-sustaining and hence sustainable farm system can be developed. The paper further concludes, that future policies and actions supporting this development could be e.g. higher construction grant or feed in tariff for organic biogas plants digesting perennial legumes as grass-clover, more knowledge of the benefits of using grass-clover in farm systems and for energetic purposes in biogas plants, co-digested with straw, and deployment of organic biogas plants in non-animal dense areas also.*

Keywords **- organic biogas, organic farming, perennial grasses, renewable energy, sustainable development**

1. INTRODUCTION

Organic farming only constitutes 1.1 % or around 50 M ha of the global arable land currently being cultivated [1] implying that agricultural practices, applying pesticides and artificial fertilizers, are widely deployed within modern agriculture. In order to develop a more sustainable agro-sector as a global community, we must identify new ways of pursuing this, by looking at some of the challenges to overcome. Lack of animal based organic fertilizer's (pig or cattle manure) distributed on organic fields, are for example hampering more arable land from being cultivated organically. Green fertilizer - crop-based only or a mix of crop/manure - is a hence a resource that potentially could supplement the use of organic animal manure as organic fertilizer, and thus sustain and expand organic farming in the future [2].

When using green fertilizer for soil improvements one normally distinguishes between organic residues directly plowed into the soil, or organic residues being digested in a biogas plant, where the nitrogen is converted to the more plant available ammonium [3], [4], and then distributed in a liquid form on farmer fields. Having emphasis on the latter in this paper, a challenge is hence to identify biomass feedstock that are appropriate for energy production, does not compete with human food and animal feed production, have enough potentials as far as gas yield, and does not contribute to negative environmental externalities, etc.

Besides this, many - especially European farmers - are increasingly confronted with the need to cultivate legumes in order to be more self-sufficient with protein supply for human food and animal feed, and to utilize leguminous plants ability to fix atmospheric N_2 through synthesis with soil bacteria, providing nitrogen to the agro-ecosystem and thereby lower the amount of artificial fertilizers needed. Furthermore, legumes also benefit the farming system by their effect as break-crop, as for example cereal diseases in the rotation, lowering the need for e.g. pesticide usage within European agriculture [5], [6].

The important role of farmers in Europe, as producers of feedstock for renewable energy production by means of biofuels - that substitutes the use of traditional fossil fuel energy carriers like coal, oil and natural gas - are also increasingly stressed by inner market policies, and frameworks supporting this [7], [8]. Globally, many countries' biofuel production, is however based on the use of e.g. maize and other types of human food or animal feed from intensive monocultures [9], and it is hence pivotal that new biomass feedstock sources for high yield energetic purposes are identified and promoted.

Emphasis of this paper is therefore threefold; to combine the challenge of increasing the amount of green fertilizer from organic biogas plants to enable an expansion in the area of organic farming, with a need to adopt to more cultivation of legumes within farming, and to increase the renewable energy production from the agricultural sector by utilizing more sustainable feedstock for biogas production. Previous studies have emphasized the use of catch crops - sometimes including legumes - to increase biomass yields per ha per year, and also analyzed its corresponding methane potentials when digested in biogas plants (see [9], [10], [11]).

According to [10] and [12] it is, however, a challenge to systematically cultivate feedstock with enough energy density for biogas production on organic farms, as yields are lower and the production costs higher. In this paper, we will highlight that by coupling different agricultural and energy related interests these challenges could be limited, and a new 'organic-agricultural-biogas'-system

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can be developed, which comply with a more sustainable development of the ago -and energetic sectors in combination.

Focus of the paper

Thus, no studies have so far looked at i) expanding the area of organic farming by increasing the amount of ‘green fertilizer’ in their analysis of legumes used for energy production. Nor, at ii) using legumes that provide Eco System Services (ESS) for agriculture and diversify cropping systems, and on legumes that iii) does not compete with human food and animal feed. We will show and discuss how the use of legumes (here perennial grass-clover) as feedstock for organic biogas, can enhance the share of organic farmland, increase the soil quality by various ESS’s and provide renewable energy based on more sustainable biomass feedstock.

Having elaborated on the focus of this paper we now turn to a description of the methodological choices taken in this study as far as data collection, and analytical framing.

2. METHODOLOGY

This section explains our data information sources and the approach to the analysis conducted.

Data retrieval

Data retrieval in this paper is based on statistical data and policy information data from e.g. public authorities, EU policy support schemes and organic farmer organizations. Knowledge on legumes, technical systems, cultivation practices and ESS, etc. are retrieved from scientific publications, by means of journal articles. Background reports on farmers operating organic biogas plants derive from the Association of Organic Farmers in Denmark (Økologisk Landsforening), and are used as secondary empirical data.

Besides this, two farm interviews and visits were conducted to collect primary empirical data on legume cultivation and the use of grass-clover in biogas plants. The interviews were conducted during the months of November 2017 and January 2018, and took place as semi-structured qualitative interviews. Fieldnotes were taken during the visits.

Framing of the analysis

The concept of ‘sustainability’ (see e.g. [13], [14]) is utilized as an analytical framing in this paper to propose on initiatives within the agricultural and energetic sector that can strengthen the sustainability contribution of the ‘organic-agricultural-biogas’-system, which we develop. We, for example, propose to *‘use local crop verities’* and to *‘diversify species*. Using local crops makes agricultural systems more robust, as they are better adapted to the local climatic zones, just like farmers are more costumed to cultivate such crops. When diversifying spices, it makes crop cultivation less vulnerable and when applied as intercropping - where two (or more) species are growing in close proximity in the same field - many environmental benefits can be obtained. Several initiatives are hence proposed in this paper with the purpose of strengthening the system developed.

Having elaborated on the analytical framing and empirical data retrieval of this paper, we now proceed to the Findings and Analysis part.

3. FINDINGS AND ANALYSIS

In the following, we will, firstly, look at the benefits and possibilities of cultivating grass-clover as crop, and, second, identify opportunities and experiences with the utilization of grass-clover as feedstock for biogas and consequently renewable energy production. In the section to follow, we hence propose on a design of a sustainable ‘organic-agricultural-biogas’-system that could increase the sustainability of the agricultural and energetic sectors’, within European countries.

Perennial legumes

When cultivating perennial legumes like grass-clover, we find that it is possible to *‘avoid unnecessary use of agro-chemical’,* as various Eco System Services (ESS) are provided by cultivation of these legumes. A study conducted by [15] for instance indicate that a system internal outputs of legume nitrogen (N)-fixation of 130-153 kg N per ha can be achieved when cultivating such crops. Other studies point to the same result, with variations between 100-200 kg N-fixation per ha [16]. Besides N-fixation legumes also provide crop rotation services, which limit agro-chemical costs by up to 25 % for e.g. cereals, and lead to yield enhancement in the following crop by up to 0.2-1.6 t. per ha [15].

Grass-clover can also be cultivation by means of intercropping with other farm crops, and even intercropped (under-sown) with other legumes, as for example with faba-beans for protein feed. Most of the farmers providing data for this paper practiced some kind of intercropping, as for instance pea, faba-bean, grass-clover with barley or wheat as companion crop. Intercropping thus *‘enhances biological interactions and synergies between the components of agro-biodiversity’*, as it facilitates a more efficient use of environmental resources for crop cultivation.

This is for example due to the reduced soil N competition when applying legume-cereal intercropping [17], increased water and nutrients uptake [18], higher yield stability and content of N in the produce [19], lower N_2O emissions from the soil, as well as better weeds and pest control by enhanced suppression by the main crop [20], [17]. Farm practices applying intercropping hence enhance the sustainability contribution of organic farming even further.

Annual intercropping is rarely practiced within European agriculture, and if so, mainly to obtain the benefits described, but also to utilize farm machinery more efficiently. Thus, when cleaning crops for weeds another type of crop can be sown at the same time. For example, grass-clover can be under-sown when cleaning faba-beans for weeds, or grass-clover can be sown together with wheat or barley. Intercropping and crop rotation applied within organic farming consequently *‘diversify species’* and provide other means of farming than the traditional cultivation of monocultures (sole cropping), which is widely applied within European agriculture [5].

Due to yield stability intercropping also assist in providing food security to a future world with still increasing pressure on crop yields for human food and animal feed supply [19]. Thus, farmers could potentially increase the cultivation of grass-clover by utilizing intercropping strategies to integrate within already existing cultivated land practices, e.g. under-sowing. Besides this, grasses from areas with natural conservation could also be harvested and increase the cultivated area of perennial grasses [2].

When assessing the options for increasing the cultivation of grass-clover traditions and climatic conditions are also important to access. Some European farmers are traditionally quite skilled in cultivating grass-clover, and *'use local crop varieties'* adapted to the local climate. Increasing the cultivation of grass-clover is therefore not a challenge as far as farm experiences and skills, but is more connected to the fact that farm practices must change to adopt more perennial grasses in their future crop rotation planning. Increasing the cultivation of grass-clover through intercropping and thus diversification of species - or by natural conservation areas or the inclusion of conversion of existing farmland - provides ESS and benefits that goes beyond traditional organic farming, and hence increases the sustainability contribution even further.

Perennial legumes and biogas

This section looks at farm practices of using grass-clover as feedstock for biogas production, and assess, whether an increase in the use of this biomass feedstock for production of digestate and energy is viable, practically and technically.

Organic biogas plants traditionally utilize a mix of different feedstock, such as manure from pig, cattle, poultry, mink, deep litter, fresh grass-clover, grass silage and cover crops. The main reason for farmers to implement organic biogas plants is to be self-sufficient with organic digestate (preferably on a liquid form), and to obtain additional income from sale of energy services [21], [22]. In a north European context energy production from biogas often derive from combined heat and power plants (CHP) supplying power to the national grid and internal usage of heat.

If a nearby heat market exists, as a small village, school, nursing home, etc., surplus heat can be exported from the farm biogas plant, which benefit the economic feasibility of the plant [23], [24]. In many other parts of the world power production is however the main energetic output and the heat are simply lost. Only few organic biogas plants currently upgrade the biogas to natural gas (pure methane), mainly due to economies of scale.

The use of grass-clover for biogas feedstock is a gas rich material (see Table 1), easy to handle, fresh or as silage, and are fed to the biogas reactor tank as biomass feedstock. Pre-treatment is normally required, as for other types of biomass feedstock, like for example deep litter and straw, and require an e.g. macerator, which homogenizes the feedstock [25]. Co-digestion of for example straw and grass-clover will normally be pre-treated together with the other types of biomass. The feedstock is then supplied to the reactor tank by a snail or mixed with the substrate in the pre-tank and pumped to the reactor tank by a knife-pump. It can, as mentioned, be a challenge to digest more solid types of feedstock, compared to liquid manure, as it floats to the surface of reactor tank and challenge the operation of the plant. The content of lignin can also require longer retention time, if not supplied as silage material.

Table 1. Gas yield of various feedstock used in farm biogas plants [21]

Biomass	% Dry matter	m^3 Biogas/t
Cattle manure	8	20
Pig manure	5	17
Deep litter (cattle)	25	96
Poultry manure	40	150
Horse manure	27	112
Grass-clover silage	30	157
Grass-clover (fresh)	50	128
Maize silage	30	166
Cereal straw	86	292
Sorted household waste	16	95
Glycerin	100	842

Practical experiences with co-silage and digestion of grass-clover with cereal straw have shown positive results, as the easy manageable grass-clover softens the cereal straw and make it easier to digest at least some of the lignin content [21]. This co-digestion of straw and grass-clover as co-silage provides high gas yields (see Table 1) and the energy intensity will consequently increase, which reduce the need for using e.g. maize that are commonly interpreted by researchers and practitioners as pivotal for obtaining a high gas yield [10]. Grass-clover is to be preferred from for example deep litter, as it loses its gas potentials relatively fast, whereas grass-clover silage provides a stable gas yield throughout the year [21]. Larger amounts of grass-clover could thus be added to the reactor tank of organic biogas plants in the future on the expense of deep litter.

Farmers operating organic biogas plants usually engage many feedstock suppliers [22]. The use of larger amounts of grass-clover from within the farm itself, would make them less dependent of feedstock supply from other farmers, as far as biomass purchase prices and amounts needed. It would also save farm expenses, connected to external machine-stations who harvest the farmer's cereals', if the fields instead are converted to cultivating perennial grass [26], [25].

A balance between the use of grass-clover, manure and other types of feedstocks however must be considered, as too much grass-clover hampers a successful digestion within the reactor tank. If the reactor tank is fed too fast by easily digestible biomass it will develop organic acids, which the methane bacteria cannot deal with [25]. Hence, perennial grass used for mono digestion has not been successfully applied yet, due to the biological balance of the microorganisms within the reactor tank [27]. Too much green biomass in the substrate will thus increase the ammonium level due to the nitrogen content in the feedstock [21].

Co-digestion with manure is therefore suggested to provide a more stable digestion process [10], [25], where the C/N relation in the feedstock is most optimal between 25 and 35 [25]. Farmers usually operate the organic biogas plants with a dry matter content of 10-20 % making the substrate manageable (pumping & stirring, etc.) and in average with six kg total N per ton biomass [22], [26].

As seen from the above the uses of grass-clover for biogas production contribute, and *'enhance the re-cycling of biomass and optimize organic matter decomposition and nutrient cycling'*. It provides benefits that goes beyond the traditional advantages of utilizing digested manure as fertilizer, being e.g. higher ammonium content favorable for plant uptake, less odor when distributing manure, and convenience of distributing a liquid digestate [4]. Co-digestion with grass-clover, for example, enhances the digestibility of straw, which is an abundant resource in many countries around the world (being wheat-, rice-, rape-straw, etc.), but challenging to digest as far as pre-treatment and retention time. Thus, increased amounts of grass-clover for biogas can facilitate the use of a not easily digestible crop, with a high gas yield potential, as feedstock. It therefore also *'enhances beneficial biological interactions and synergies among the components of agro-biodiversity'*.

To increase the sustainability contribution of farms operating organic biogas plants it is favorable in the future to convert machinery etc. to run on biogas, or other types of renewable fuels, instead of fossil fuels. This could be based on farm self-supply, but currently require upgrading and compression of the biogas for transportation usage [28], and would only be a real option on large scale organic biogas plant that have already applied upgrading facilities. This would hence *'Minimize the use of external, non-renewable resources (including fossil fuels)'* on organic farms, where the use of machinery is widely deployed. This is caused by organic farmers using more mechanical treatment of soil etc., compared to conventional farming, due to less pesticides applied and hence the need to clean for weeds, etc. More self-sufficiency in feedstock from within the farm will further minimize the expenses and fuel utilization connected with purchase and transportation of biomass from various suppliers, which, according to empirical data, lead to high expenses [21].

It should be noted that some European countries restrict the use of agricultural crops ('energy crop') as feedstock for energy production, which include biomass like for example perennial grass (e.g. grass-clover), maize, beet and cereals (whole crop and grains). This is for instance the case in Denmark, but organic arable land and farmland that have not been plowed for the last five years, is however [29]. Within all EU member countries any restrictions in the use of 'energy crops' is made with point of departure in the Renewable Energy Directive (2009) through the Sustainability Criteria [7].

4. DISCUSSION

In the following section we will elaborate on the 'organic-agricultural-biogas'-system, which could be applied in connection to organic crop and livestock farms to enhance the use of perennial grass as feedstock for biogas production and facilitate the expansion of organic farming. At the end of the section we will shortly propose on policies and actions that can act as drivers for a future deployment of such system.

Design of the 'organic-agricultural-biogas'-system

The 'organic-agricultural-biogas'-system is depicted in Figure 1 below in which e.g. 20 % of the farmland is designated the cultivation of grass-clover with a total contribution of 200-300 kg N per ha, of which 100 kg N per ha is used as fertilizer on e.g. 40 % of the farmland. With the implementation of a biogas plant, and feedstock supplied from the system as outlined, it is possible for organic crop farmers to apply more roughage or grass-clover in their crop rotation than usual, and in this way achieve some of the robustness that is currently achieved within organic livestock farming. *Crop farmers* cultivating grass-clover can thus grow more demanding crops with high dry matter content that provides competition to weed. Grass-clover cuts will both sanitize for root weeds and provide nitrogen and feedstock for biogas production [25].

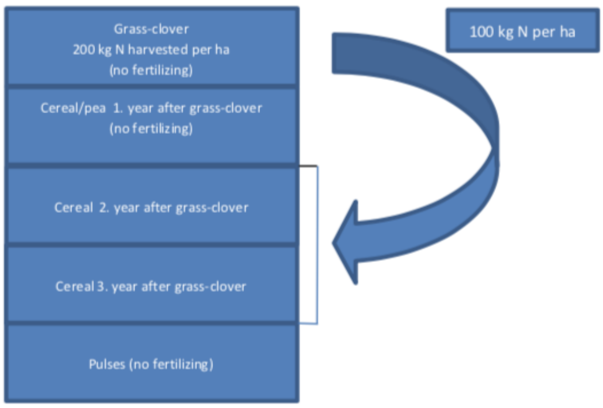

Fig. 1: Supply of nitrogen from digested grass-clover to other parts of the farmland [25]

Crop farmers can, moreover, supply whole crop silage from weed contaminated fields to the biogas plant, and in this way remove weeds and utilize the biomass for energy production. Previously, this was only applied by livestock farmers [25]. Crop farmers can also benefit from the cultivation of perennial grasses on extensively cultivated natural areas etc. that are harvested in connection with natural conservation. *Livestock farmers* also gain from the system, even though they already possess livestock manure and a more favorable crop rotation system, but they can now sell surplus organic digestate to local crop farmers. Deploying such 'organic-agricultural-biogas'-system assist in a healthier crop rotation, which builds up the content of organic matter in the soil and increase the soil quality [25]. With 15- 20 % grass-clover in the crop rotation the following benefits are thus obtained of which some are already emphasized under ESS:

*Nitrogen -'engine' created.
*Lower or no fertilizing needs.
*Feedstock for biogas provided that does not compete with human food or animal feed.
*A high energetic biomass (high gas yield especially when co-digested with straw silage).
*A sanitating crop as far as weeds etc.
*A crop building up organic matter in the soil (carbon).

The 'organic-agricultural-biogas'-system proposed here, could potentially facilitate that conventional crop farmers reorganize their farms to become organic crop farmers in areas with low animal density. An organic biogas plant implemented in such areas will provide higher nutrient supply security. With more organic digestate in the areas conventional farmers might be more convinced to 'take the jump' and become organic farmers.

Policies and actions

To support the deployment of organic biogas plants and thus an expansion of the organic arable farmland, we suggest future policies and actions to focus on the following aspects:

-Provide more knowledge dissemination of the benefits of cultivating perennial legumes as grass-clover as far as ESS, and the monetary value of digestate when used as field fertilizer.

-Provide more knowledge of the benefits of using grass-clover in farm systems and for energetic purposes in biogas plants, preferably co-digested with straw being an abundant resource in many countries.

-Set up a subsidy scheme (higher construction grant or higher feed-in tariff) for the implementation of organic biogas plants using grass-clover.

-Provide assistance in mapping and planning for feedstock and digestate supply to/from organic biogas plants, as the density of organic farms are low, the transportation distances long and the availability of resources limited.

-Plan for organic biogas plants also in non-animal dense areas (supported by the above actions).

-Establish more organic biogas plants, as side-lines (separate reactor tank and digestate outlet) on existing conventional biogas plants.

5. CONCLUSION

Various environmental benefits and yield enhancement of cultivating perennial grasses (grass-clover) can be obtained as far as ESS, which includes lower need for artificial fertilizer caused by legume nitrogen (N_2)-fixation, reduced need for pesticide for pests and weeds control, and consequently yield enhancements. Intercropping and crop rotation with grass-clover based on local cultivars also increase yield stability, provide higher N-content in crops, lower (N_2O) emissions from the soil - typically caused by artificial fertilizer - and better weed and pest control through enhanced suppression by the main crop, etc. We found that increasing the cultivation of grass-clover does not challenge farmers as far as skills and traditions, and that expansion of grass-clover yields is viable.

This study also indicates that ESS's achieved, in combination with intercropping and diversity of spices - potentially increasing grass-clover yields without including additional farmland - can strengthen the sustainability contribution of organically cultivated grass-clover for biogas production even further.

The current farm practices of using perennial grass-clover as feedstock for biogas production, sustain a further expansion of cultivating this crop. The use of grass-clover as biogas feedstock provides a gas rich biomass that farmers handle relatively easy, either as a fresh crop or as silage, fed into the reactor tank without major challenges. Co-digestion of straw and grass-clover as co-silage shows high gas yields and is therefore a promising future feedstock mix for organic biogas plants together with animal manure.

The analysis reviled that biogas farmers see advantages in cultivating additional amounts of grass-clover on their farms, as it makes them less dependent of feedstock supply (import) from other farmers, as far as purchase prices and quantities needed. It could also provide cost savings, if arable land was converted to the cultivation of perineal grasses, as the expenses to machine-stations harvesting cereals', would decrease.

Some European organic farmers who operate biogas plants are experienced in co-digesting grass-clover and manure, as it provides a more stable process within the reactor tank and the amount of grass must thus not be too high hampering the digestion process. Using grass-clover, co-digested with straw silage, for production of organic digestate and renewable energy, will hence provide sustainability benefits beyond the traditional advantages of biogas production. A challenge for organic farmers producing biogas - utilizing perennial legumes or not - is however the fossil fuel usage connected to intensive mechanical works on organic farming. Alternative fuels must be applied in the future, e.g. compressed biogas, for farm machinery usage and transport.

We suggest to establish an 'organic-agricultural-biogas'-system in which e.g. 20 % of the farmland is designated the cultivation of grass-clover with a total contribution of 200-300 kg N per ha, of which 100 kg N per ha can be used on 40 % of the farmland. The design of the system provides many benefits for both organic crop and livestock farmers, such as the creation of a nitrogen -'engine', lower or no fertilizing needs, feedstock for biogas production that does not compete with human food or animal feed, provide a high energetic biomass (high gas yield), will sanitate farm crops as far as weeds etc., and will contribute to the builds up of organic matter in the soil (carbon).

Finally, we conclude that future policies and actions supporting this development could be, for instance, higher construction grant or feed in tariff for organic biogas plants digesting perennial legumes as grass-clover, more knowledge of the benefits of using grass-clover in farm systems and for energetic purposes in biogas plants co-digested with straw, and that organic biogas plants should be implemented in non-animal dense areas also.

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